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UTILITY PATENT APPLICATION TRANSMITTAL

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APPLICATION ELEMENTS
See MPEP chapter 600 concerning utility patent application contents.

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1. ☒ *Fee Transmittal Form (e.g. PTO/SB/17)
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2. ☒ Specification — Total pages: 22
   (preferred arrangement set forth below)
   - Descriptive Title of the Invention
   - Cross References to Related Applications
   - Statement Regarding Federally Sponsored Research
   - Reference to Microfiche Appendix
   - Background of the Invention
   - Brief Summary of the Invention
   - Brief Description of the Drawings *(if filed)*
   - Detailed Description
   - Claim(s)
   - Abstract of the Disclosure
3. ☒ Drawing(s) *(35 USC 113)* — [Total Pages: 2
4. Oath or Declaration — [Total Pages: 2
   a. ☒ Newly executed (original or copy)
   b. ☐ Copy from a prior application (37 CFR §1.63(d))
   (for continuation/divisional with Box 16 completed)
      I. ☐ Deletion of Inventor(s)
      Signed statement attached deleting inventor(s) named in the prior application, see 37 CFR §§1.53(d)(2) and 1.33(b)

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5. ☐ Microfiche Computer Program (Appendix)
6. Nucleotide and/or Amino Acid Sequence Submission (if applicable, all necessary)
   a. ☐ Computer readable copy
   b. ☐ Paper copy (identical to computer copy)
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ACCOMPANYING APPLICATION PARTS

7. ☒ Assignment Papers (cover sheet & document(s))
8. ☒ 37 CFR §3.73(b) Statement *when there is an assignee* ☒ Power of Attorney
9. ☐ English translation document *(if applicable)*
10. ☐ Information Disclosure Statement (IDS) /PTO 1449 ☐ Copies of IDS Citations
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A METHOD OF DIRECTIONAL FILTERING
FOR POST-PROCESSING COMPRESSED VIDEO

BACKGROUND OF THE INVENTION

The present invention relates to post-processing of decompressed digital images and, more particularly, to a method of directional, selective filtering of decompressed images.

Transform coding is a common method for compressing digital images. For examples, transform coding is featured in the JPEG (ISO 10918) standard related to still images and the MPEG-2 (ISO/IEC 13818) standard related to motion video. Generally, transform coding involves subdividing an image into smaller blocks or groups of pixels, applying a "reversible transform" (such as the Discrete Cosine Transform (DCT)) to the pixels of the blocks, quantizing the frequency coefficients produced by the transform, and coding of the results. While transform coding can achieve a high compression ratio, information in the original image is discarded in the compression-decompression process degrading the decompressed image, especially in video sequences with considerable motion.

Decompressed transform coded images may include visible artifacts of the compression-decompression process. A common artifact is the "blocking" effect, also known as "grid noise." The blocking effect is the result of the process of approximating each of the frequency coefficients produced by the transform as one of a limited number of permitted values during the quantization step. The encoder selects a quantization parameter establishing the difference between successive permitted values and assigns each frequency coefficient to the nearest permitted value. As a result of the "rounding off" during quantization, adjacent pixels may have different quantized values even though their colors were nearly the same in the original image causing individual blocks to be visible in the

decompressed image. This is a particular problem in areas of uniform color and along color boundaries. In addition, the decompressed image may exhibit "staircase noise," a term which is descriptive of an appearance of an edge in the image. The staircase appearance is the result of enhancement of the blocking effect for blocks lying across an edge in an image. A third artifact of interest in decompressed images is the so called "ringing artifact" that produces jagged or fuzzy lines in the vicinity of sharp edges. All of these artifacts can be annoying to viewers of the image. Accordingly, images are processed after decompression (post-processed) to reduce or eliminate some or all of these artifacts.

Several methods have been used to remove or reduce annoying artifacts in decompressed images. Some methods attempt to recover the original image from the decompressed image and knowledge of the smoothness properties of the image before compression. Generally, these methods are complex and often iterative limiting their usefulness in real time video applications.

Filtering may also be applied to the image pixels to reduce artifacts of the compression process. For example, filtering may be applied to pixel segments of rows or columns normal to the block boundaries to smooth the color or grayscale transition across the boundary, thereby reducing the blocking effect. Classification of the block's neighborhood and filtering based on the classification can be part of the filtering process. While filtering pixel segments normal to block boundaries is useful in addressing the blocking effect, it does not necessarily address ringing artifacts. Further, edges may be filtered and some portions of diagonal edges may be filtered repeatedly, adversely impacting the sharpness of the decompressed image.

What is desired, therefore, is a computationally conservative method of post-processing a decompressed image that effectively addresses both blocking and ringing artifacts but preserves the sharpness of edges in the image.

SUMMARY OF THE INVENTION

The present invention overcomes the aforementioned drawbacks of the prior art by providing a method of post-processing a decompressed image comprising the steps of establishing a filtering axis aligned relatively parallel to an image edge in a block of image pixels and selectively filtering a plurality of pixels arrayed substantially parallel to the filtering axis. Filtering the pixels of a block in a direction substantially parallel to an image edge in the block minimizes any impact on the sharpness of the edge. Further, the method conserves computational resources by selecting pixels for filtering that exhibit a difference from their neighbors that is likely to produce a visual artifact. Pixels that are members of blocks not likely to exhibit a blocking effect are not filtered. Further, pixels at block boundaries having values sufficiently close so as not to produce a noticeable artifact and pixels representing details are not filtered. The method can also be applied separately to the images contained in individual fields of interlaced video to avoid image complications arising from the separate processing, including compression, of the fields.

The foregoing and other objectives, features and advantages of the invention will be more readily understood upon consideration of the following detailed description of the invention, taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic drawing of pixels of an exemplary area of a decompressed image.

FIG. 2 is a flow diagram of the post-processing method of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

In the transform coding process an N (pixel) x N (pixel) image is subdivided into nxn sub-images or blocks and the transform is applied to the individual pixels on a block by block basis. For example, in the Discrete Cosine Transform (DCT) compression process utilized by in the JPEG (ISO 10918) and MPEG-2 (ISO/IEC 13818) image compression processes the image is subdivided into 8X8 blocks for coding. FIG. 1 illustrates a portion of a larger image 10 that has been subdivided into blocks, such as the block 12 that is bounded by the block boundaries 14, 16, 18, and 20. Pixels outside of the area bounded by the block boundaries are pixels included in adjacent blocks. An image edge 22, formed by the boundaries of pixels of a first 24 and second 26 color divides the block 12 diagonally. It is understood that a block of pixels, as used herein, may be any plurality of pixels defining any pattern.

Decompressed images may exhibit several artifacts of the compression-decompression process. The most prevalent artifact of compression is the blocking effect where the blocks created for image compression are visually perceptible in the decompressed image. In the DCT transform coding compression process, the spatial domain signal for a block is converted to a block of coefficients in the frequency domain by the application of the transform. The resulting frequency coefficients are quantized or approximated as one of a limited number of discrete values permitted by the encoder. Since large areas of an original image may be of relatively uniform color or grayscale, the "rounding off" process performed by the encoder may result in pixels of nearly the same original color being assigned quantized values that are visually significantly different. When the image is decompressed, the color or grayscale difference of the pixels may be sufficient to be noticeable. This is a particular problem at the boundaries of adjacent blocks in areas of relatively uniform color. The severity of the blocking effect is a function of the distance between successive potential quantized values or the quantization parameter selected by the encoder. Post-processing (often by filtering) may be applied to smooth the change across block boundaries to reduce

or eliminate the blocking effect or grid noise.

Filtering a segment of a horizontal row or vertical column of pixels along each boundary of each block of an image is a computationally resource intensive process. In addition, filtering a column or row of pixels extending to the center of the block 12 would result in filtering of the image edge 22. Some portions of a diagonal image edge, such as edge 22, may be filtered more than once. As a result, the sharpness of edges in the decompressed image will be degraded. The present inventor realized that computational resources can be conserved by selectively filtering pixels within selected blocks of an image where an artifact may be a problem. Further, the inventor realized that the sharpness of edges and, therefore, the quality of the decompressed image can be improved by selectively filtering pixels along an axis aligned generally parallel to the direction of an image edge. In the present invention, the direction of an image edge is detected and filtering is selectively applied to pixels arrayed along a filtering axis which aligned relatively parallel to the direction of an image edge in a block.

In addition to the blocking effect, decompressed images may exhibit ringing artifacts that often appear as noisy lines in the vicinity of and approximately paralleling an image edge. In FIG. 1 a ringing artifact is illustrated by pixels of a third color 28 in the vicinity of the edge 22. A decompressed image may also exhibit "staircase noise," a term which is descriptive of an appearance of an edge in the image. The staircase appearance is the result of enhancement of the blocking effect for blocks lying across an edge 22 in an image.

The steps of the post-processing technique of the present invention are illustrated in FIG. 2. To avoid over smoothing the image and conserve computational resources, filtering is selectively applied to the pixels of selected blocks of the image. In a block selection step, the quantization parameter (QP) for each block is extracted from the data stream and compared to a predetermined quantization parameter threshold (QP_THR) 102. The quantization parameter threshold is a selected maximum distance between quanta that produces a visually acceptable transition across the block boundary. If the quantization

parameter is less than the threshold, the quantization error is not likely to create significant grid noise and an objectionable blocking artifact. If this is the case, the method selects the next block for examination 104 without filtering the current block. If the quantization parameter exceeds the quantization parameter threshold, the block is designated for filtering.

If a block of pixels is to be filtered, the most dominant direction of an image edge in the block is determined 106. The edge direction is determined by comparing pixels in the vicinity of opposing boundaries of the block and located on projections of candidate filtering axes. Referring again to FIG. 1, the edge detection investigation may be performed in the directions of four candidate axes; horizontal (k=0) 30, vertical (k=2) 32, and the 45° diagonals (k=3) 34 and (k=1) 36, to determine the dominant direction of the exemplary edge 22 in the block 12. The investigation could proceed along different, additional or intermediate candidate axes (for example, 22.5°) but the required additional computation may not be justified by the improvement in the quality of the decompressed image.

Since a block loses much of its high frequency information in the compression process, inferring the direction of an image edge from pixels within the block can be difficult. Examining pixels that are members of neighboring blocks and adjacent to the block boundaries 14, 16, 18, and 20 increases the area of the image subject to examination and improves the accuracy of the results. Corresponding pairs of pixels to be compared are located along projections parallel to each of the candidate axes 30, 32, 34, and 36 and in the vicinities of opposing block boundaries. For example, projections 38 and 40 parallel to candidate axis 36 are used to identify pixels (1,0) 42 and (0,1) 44 and (3,0) 46 and (0,3) 48 in the vicinities of block boundaries 14 and 18 for comparison. Sub-sampling by a factor of two has been found to produce sufficient data points to identify the dominant edge direction and reduces the computational requirements. As a result, five pairs of pixels are investigated for the horizontal (k=0) 30 and vertical (k=2) 32 axes and nine pairs of pixels are investigated for the diagonal

axes (k=1) 36 and (k=3) 34. Sub-sampling by a factor of two produces an exemplary data set as follows for an 8x8 block, where P_k^1 and P_k^2 are pixels of corresponding pairs on opposing block boundaries:

k	P_k^1	P_k^2
0	{(0,0), (1,0), . . . , (N+1,0)}	{(0,N+1), (1,N+1), . . . , (N+1,N+1)}
1	{(0,1), . . . , (0,N+1), . . (N,N+1)}	{(1,0), . . . , (N+1,0), . . . , (N+1,N)
2	{(0,0), (0,1), . . . , (0,N+1)}	{(N+1,0), (N+1,1), . . . ,(N+1,N+1)}
3	{(0,N), . . . , (0,0), . . . ,(N,0)}	{(1,N+1), . . . , (N+1,N+1), . . . (N+1,1)}

The dominant direction of an image edge in a pixel block is identified by the candidate axis corresponding to the minimum sum of the mean absolute differences of the pixel values for each of the pluralities of corresponding pixels selected for investigation. In other words:

$$k_{min} = arg\ \mathrm{MIN}_{\{0 \le k \le 3\}} | P_k^1 - P_k^2 | / \mathrm{DIM}(P_k^1)$$

where:

$| P_k^1 - P_k^2 | / \mathrm{DIM}(P_k^1)$ = the mean absolute difference of the corresponding pixels in the set of projection data in the direction of axis k

k_{min} = the candidate axis returning the minimum argument

The difference between pixels at opposing boundaries on projections parallel to the edge 22 is assumed to be less than the differences between pixels sampled in the direction of candidate axes 30, 32, and 34 which lie on opposites the significant color or grayscale difference that characterizes an edge, such as edge 22. The candidate direction that produces the minimum sum is taken as the dominant direction of the edge 22 in the block 12 for the purpose of orienting the filtering axis for filtering the pixels of block 12.

Following determination of the dominant image edge direction, groups of contiguous pixels 49 (V_0, . . . ,V_9) (filtering segments) (indicated by a bracket) bisected by the block boundary 14 and parallel to the identified edge direction or

filtering axis are identified for selective low pass filtering 108.

To avoid over smoothing the image, the two pixels of the filtering segment adjacent to the block boundary (V_4 and V_5) 50 and 52 are tested against two thresholds 110. First, if the absolute value of the difference between the pixels (V_4 and V_5) 50 and 52 adjacent to the block boundary 14 is greater than twice the quantization parameter (QP), the pixels likely represent an image edge and filtering is not applied to avoid reducing the sharpness of the edge. On the other hand, filtering is not applied if the absolute value of the difference between pixels 50 and 52 adjacent to the block boundary 14 is less a predefined boundary threshold (BD_THR) because the difference between the colors or grayscale of the pixels is insufficient to cause a visible blocking artifact. If the difference between pixels 50 and 52 of the filtering segment 48 adjacent to the block boundary is outside the upper and lower bounds established by these tests, then the next filtering segment is selected 112 without applying filtering to the current segment.

If the difference between the pixels 50 and 52 adjacent to the boundary is within the upper and lower bounds, filtering of the segment is warranted and the continuity of the color or grayscale along the filtering segment is checked 114. A significant difference between adjacent pixels in a filtering segment, except at the block boundary, is a probable indication of a detail within the block. The purpose of the discontinuity check 114 is to detect such a variation and limit filtering to a range of pixels within the segment so that filtering is not applied to the pixels representing the detail. Starting at V_4 50, the difference between the value of V_4 (V_i) and next contiguous pixel further removed from the boundary (V3) 54 is compared to a threshold (THRED). Likewise, the difference between pixel V_3 54 and pixel V_2 56 and each successive pair of pixels farther from the block boundary 14 will be compared to the threshold (THRED). If the difference for a pair of pixels exceeds the threshold (THRED), the pixel nearer the block boundary 14 is chosen as the lower bound to the filtering segment 49. Likewise, a discontinuity check is performed, beginning at V_5 52, to establish an upper bound

to the segment. A filtering range comprising the portion of the filtering segment 49 including the pixels between the upper and lower bound produced by the discontinuity check ($V_{LB} \ldots V_{UB}$) and including at least one pixel on each side of the boundary is filtered. The threshold may be a function of the quantization parameter (QP) and the absolute value of the difference between the pixels adjacent to the boundary ($|V_4 - V_5|$). The threshold also may differ for blocks with different characteristics. For example, blocks might be characterized on the basis of the mean difference between pixels on opposing boundaries of the block as identified in the image edge direction identification step 108. For example, a block might be typified as:

(a) simple, strong edge type if: Min_dif < THR_edge 1 and
Max_dif - Min_dif > THR_edge 2

(b) smooth if: Max_dif < THR_smooth

(c) complex if: the relationship of Min_dif and Max_dif is otherwise

where: Min_dif = the mean absolute difference in values corresponding to k_{min}

Max_dif = the mean absolute difference in values corresponding to k_{max}

THR_edge 1= threshold edge 1

THR_edge 2 = threshold edge 2

THR_smooth = threshold of smooth transistion

$k_{min} = arg\ MIN_{\{0 \leq k \leq 3\}} | P_k^1 - P_k^2 | / DIM (P_k^1)$

$k_{max} = arg\ MAX_{\{0 \leq k \leq 3\}} | P_k^1 - P_k^2 | / DIM (P_k^1)$

$|P_k^1 - P_k^2| / DIM(P_k^1)$ = the mean absolute difference of the corresponding pixels in the set of projection data in the direction of axis k

k_{min} = the axis producing the minimum argument

k_{max} = the axis producing the maximum argument

For example, the threshold (THRED) might be increased to facilitate more aggressive filtering of filtering segments in blocks classified as possessing a simple, strong edge. The threshold (THRED) can also be set to a level sufficient to avoid filtering details in the block while allowing filtering of the pixels of the ringing artifact 28. Pixel repetition or symmetric extension may be used for filtering pixels near the segment boundary (V_{LB}, . . . V_{UB}).

Following determination of the filtering range, the pixels of the filtering range ($V_{LB} \ldots V_{UB}$) are filtered 116 and the method selects the filtering segment for processing 112. Filtering is necessary only along the left vertical boundary 14 and the lower horizontal boundary 20 of the block 12 because filtering is usually applied in the direction of the raster scan and the remaining block boundaries 16 and 18 are subject to filtering when the neighboring blocks are filtered. Any low pass filter may be used for filtering the filtering range. A seven tap filter that has been found to produce acceptable image quality can be implemented as described in TABLE A.

In addition, a short filter mode may also be provided for in the method of the present invention. A large variation in intensity for the pixels of the filtering segment 49 indicates that the segment is in an area of the image 10 having a high level of detail texture. If this is the case, the short filtering mode can be selected and the values of the two pixels 50 and 52 adjacent to the block boundary 14 replaced by their average value to reduce the blocking effect.

The method of the present invention is also useful for post-processing the image of an interlaced video field. Since the two fields often undergo different operations during compression (for example, motion estimation or compensation and DCT coding), it is advantageous to apply post-processing separately to the

images represented by the individual fields. Applying post-processing separately to the fields avoids the complication of block classification and confusing an intensity change between fields (resulting from either field capture or compression) as an image edge. Identifying an intensity change between fields as an image edge is a particular problem at the boundaries of moving objects. Slightly better performance may also be possible if adaptive separation is based on the mode of compression of each macro-block (field or frame motion compensation).

All the references cited herein are incorporated by reference.

The terms and expressions that have been employed in the foregoing specification are used as terms of description and not of limitation, and there is no intention, in the use of such terms and expressions, of excluding equivalents of the features shown and described or portions thereof, it being recognized that the scope of the invention is defined and limited only by the claims that follow.

TABLE A

Implementation of a seven tap filter

****

```
/* LPF7: (1 2 3 4 3 2 1)/16 */
        /* v[i]:  segment of input data to be filtered
           u[i]:  segment of output data
                  LB, HB: lower bound and upper bound of the smaller
                  segment that is actually filtered */
        for(I=-3, psum=4; I<=3;I++)
         {
            if(I+LB>=0) psum+=v[I+LB];
            else psum+=v[0];
         }
        for (I=LB; I<=HB; I++)
         {
            switch (I)
             {
             case 1:
              u[1] = (((psum + v[1]) << 1)+(v[2] - v[4])) >> 4;
              psum+=v[5]-v[0];
              break;
             case 2:
              u[I] = (((psum + v[I]) << 1)+(v[3]+v[1]) - (v[5] + v[0])) >> 4;
              psum+=v[6]-v[0];
              break;
             case 3:
              u[I] = (((psum + v[I]) << 1)+(v[4]+v[2]) - (v[6] + v[0])) >> 4;
              psum+=v[7]-v[0];
              break;
```

```
case 4:
  u[l] = (((psum + v[l]) << 1)+(v[5]+v[3]) - (v[7] + v[1])) >> 4;
  psum+=v[8]-v[1];
  break;
case 5:
  u[l] = (((psum + v[l]) << 1)+(v[6]+v[4]) - (v[8] + v[2])) >> 4;
  psum+=v[9]-v[2];
  break;
case 6:
  u[l] = (((psum + v[l]) << 1)+(v[7]+v[5]) - (v[9] + v[3])) >> 4;
  psum+=v[9]-v[3];
  break;
case 7:
  u[l] = (((psum + v[l]) << 1)+(v[8]+v[6]) - (v[9] + v[4])) >> 4;
  psum+=v[9]-v[4];
  break;
case 8:
  u[l] = (((psum + v[l]) << 1)+(v[7]-v[5])) >> 4;
  break;
}
}
```

What is claimed is:

1. A method of post-processing a decompressed image comprising the steps of:

   (a) establishing a filtering axis aligned relatively parallel to an image edge in a block of image pixels; and

   (b) selectively filtering a plurality of pixels arrayed substantially parallel to said filtering axis.

2. The method of claim 1 wherein the step of establishing said filtering axis comprises the steps of:

   (a) identifying a first pixel and a second pixel located on a projection parallel to a candidate axis; said first pixel located in a vicinity of a first boundary of said block and said second pixel located in a vicinity of a second boundary;

   (b) comparing said first and said second pixel;

   (c) repeating steps (a) and (b) for a plurality of said candidate axes; and

   (d) designating as said filtering axis said candidate axis associated with a comparison of said first and said second pixel having a predefined relationship to corresponding comparisons for other said candidate axes.

3. The method of claim 2 wherein said relationship between said comparison is a minimum of a mean of a difference between a plurality of said first and said second pixels identified in connection with a candidate axis.

4. The method of claim 1 wherein the step of selectively filtering a plurality of pixels arrayed substantially parallel to said filtering axis comprises the steps of:

   (a) designating a segment of contiguous pixels to be subject to

filtering if a comparison of a pair of pixels of said segment immediately adjacent to a boundary of said block satisfies a predetermined relationship; and

(b) selectively filtering said pixels of said segment.

5. The method of claim 4 wherein said predetermined relationship comparing said pair of pixels adjacent to said boundary comprises a upper boundary threshold for a difference between said pair of pixels.

6. The method of claim 4 wherein said predetermined relationship for comparing said pair of pixels adjacent to said boundary comprises a lower threshold for a difference between said pair of pixels.

7. The method of claim 6 wherein said lower threshold comprises a function of a quantization parameter applicable to said block.

8. The method of claim 1 wherein the step of selectively filtering a plurality of pixels arrayed substantially parallel to said filtering axis comprises the steps of:

(a) designating a segment of contiguous pixels to be subject to filtering if a comparison of a pair of pixels of said segment immediately adjacent to a boundary of said block satisfies a predetermined relationship;

(b) identifying at least one pixel on each side of said boundary as a filtering range by successively comparing contiguous pairs of pixels further removed from said boundary to a continuity threshold; and

(c) filtering said pixels of said filtering range.

9. A method of post processing a decompressed image comprising the steps of:

(a) selecting a block of image pixels for filtering as a function of a quantization parameter and a quantization parameter threshold;

(b) establishing a filtering axis relatively parallel to an image edge in said block;

(c) identifying a filtering segment comprising a plurality of contiguous pixels arrayed substantially parallel to said filtering axis and intersected by a boundary of said block; and

(d) selectively filtering said pixels of said filtering segment.

10. The method of claim 9 wherein the step of establishing a filtering axis relatively parallel to an image edge in said block comprises the steps of:

(a) designating a plurality of candidate axes;

(b) identifying a first pixel and a second pixel located on a projection parallel to a candidate axis, said first pixel located in a vicinity of a first boundary of said block and said second pixel located in a vicinity of a second boundary;

(c) determining a difference between said first pixel and said second pixel;

(d) repeating steps (b) and (c) for said plurality of candidate axes;

(e) identifying as said filtering axis said candidate axis corresponding to a function of a minimum difference between said first and said second pixels.

11. The method of claim 9 comprising the further step of designating said filtering segment subject to filtering if a pair of pixels of said filtering segment adjacent to said boundary satisfies a predetermined relationship to a threshold.

12. The method of claim 11 wherein the step of designating said filtering segment subject to filtering a pair of pixels of said filtering segment adjacent to a

boundary of said block satisfies a predetermined relationship to a threshold comprises the steps of:

(a) comparing a difference between said pair of pixels to an upper boundary threshold; and

(b) comparing said difference between said pair of pixels to a lower boundary threshold.

13. The method of claim 12 wherein said lower boundary threshold is a function of a quantization parameter for said block.

14. The method of claim 9 comprising the further steps of:

(a) designating at least one pixel on each side of said boundary as a filtering range; and

(b) filtering said pixels of said filtering range.

15. The method of claim 14 wherein the step of designating at least one pixel on each side of said boundary as a filtering range comprises the steps of:

(a) selecting a pixel of said filtering segment adjacent to said boundary for inclusion in said filtering range; and

(b) successively including in said filtering range a next contiguous pixel until a difference between a last pixel included in said filtering range and said next contiguous pixel exceeds a continuity threshold.

16. The method of claim 15 wherein said continuity threshold is a function of a quantization parameter for said block.

17. The method of claim 15 wherein said continuity threshold is a function of a difference between a first pixel located in a vicinity of a first boundary of said block and a second pixel located in a vicinity of an opposing second boundary

of said block.

18. A method of post processing a decompressed image comprising the steps of:

(a) identifying a block of image pixels defined by a block boundary;

(b) comparing a quantization parameter applicable to said block to a threshold quantization parameter;

(c) selecting a pixel pair arrayed on each of a plurality of projections parallel to a plurality of candidate filtering axes, if said block quantization parameter exceeds said threshold quantization parameter;

(d) summing the mean difference between pixels of said pixel pair for each of said plurality of projections for each of said candidate filtering axes;

(e) selecting said candidate filtering axis corresponding to a least of said sum of said difference between pixels of said pixel pair as a filtering axis;

(f) identifying a filtering segment comprising a plurality of filtering segment pixels arrayed in a direction parallel to said filtering axis;

(g) identifying a filtering range comprising at least one said filtering segment pixel on each side of said block boundary; and

(h) filtering said filtering segment pixels of said filtering range to smooth said decompressed image.

19. The method of claim 18 further comprising the steps of:

(a) comparing a difference between pixels of a contiguous filtering segment pixel pair to a continuity threshold;

(b) repeating step (a) for filtering segment pixel pairs located successively more remote from said block boundary until said difference exceeds said continuity threshold; and

(c) limiting said filtering range to an array of successively more remote filtering segment pixels on each side of said block boundary; each pixel being a member of a filtering segment pixel pair characterized by said difference being less said continuity threshold.

20. A method of post-processing interlaced video comprising the steps of:

(a) establishing a filtering axis aligned relatively parallel to an edge in a block of pixels of a first interlaced field;

(b) selectively filtering a plurality of pixels of said block of said first interlaced field arrayed substantially parallel to said filtering axis;

(c) establishing a filtering axis aligned relatively parallel to an edge in a block of pixels of a second interlaced field; and

(d) selectively filtering a plurality of pixels of said block of said second field arrayed substantially parallel to said filtering axis.

21. The method of claim 20 wherein the step of establishing said filtering axis comprises the steps of:

(a) identifying a first pixel and a second pixel located on a projection parallel to a candidate axis; said first pixel located in a vicinity of a first boundary of a block and said second pixel in a vicinity of a second boundary of said block;

(b) comparing said first and said second pixel;

(c) repeating steps (a) and (b) for a plurality of said candidate

axes; and

(d) designating as said filtering axis said candidate axis associated with a comparison of said first and said second pixel having a predefined relationship to corresponding comparisons for other said candidate axes.

22. The method of claim 21 wherein said relationship between comparisons is a minimum of a difference between said first and said second pixel.

23. The method of claim 20 wherein the step of selectively filtering a plurality of pixels arrayed substantially parallel to said filtering axis comprises the steps of:

(a) designating a segment of contiguous pixels to be subject to filtering if a comparison of a pair of pixels of said segment immediately adjacent to a boundary of said block satisfies a predetermined relationship; and

(b) selectively filtering said pixels of said segment.

24. The method of claim 20 wherein said predetermined relationship comparing said pair of pixels adjacent to said boundary comprises a upper boundary threshold for a difference between said pair of pixels.

25. The method of claim 20 wherein said predetermined relationship for comparing said pair of pixels adjacent to said boundary comprises a lower threshold for a difference between said pair of pixels.

26. The method of claim 25 wherein said lower threshold comprises a function of a quantization parameter applicable to said block.

27. The method of claim 20 wherein the step of selectively filtering a plurality of pixels arrayed substantially parallel to said filtering axis comprises the steps of:

(a) designating a segment of contiguous pixels to be subject to filtering if a comparison of a pair of pixels of said segment immediately adjacent to a boundary of said block satisfies a predetermined relationship;

(b) identifying at least one pixel on each side of said boundary as a filtering range by successively comparing contiguous pairs of pixels further removed from said boundary to a continuity threshold; and

(c) filtering said pixels of said filtering range.

ABSTRACT OF THE DISCLOSURE

A method of post-processing decompressed images includes identification of the direction of an image edge in a pixel block of the image and filtering applied along the boundary of the block in a direction substantially parallel to the detected image edge. Pixels are selected for filtering on the basis of the quantization parameter of the block of which they are members, the relative difference between pixels adjacent to the block boundary, and significant changes value of pixels in a filtering segment. Filtering is applied parallel to the detected edge to protect the sharpness of the edge while reducing or eliminating blocking and ringing artifacts. A method of separately post-processing fields of interlaced video eliminating complications arising from separate compression of the fields is also disclosed.

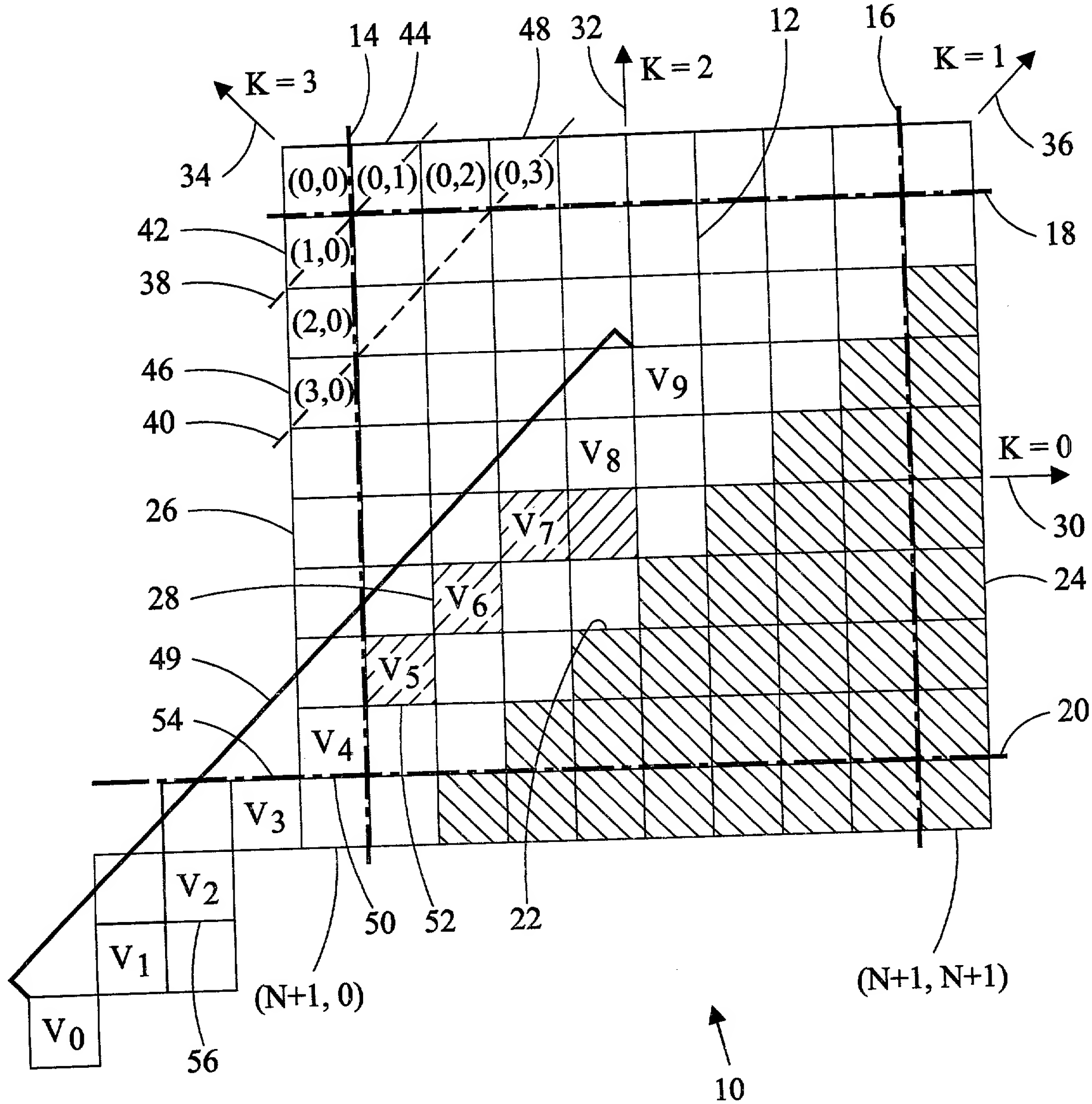
14
44
48
32
12
16
K = 3
K = 2
K = 1
34
36
(0,0)
(0,1)
(0,2)
(0,3)
18
42
(1,0)
38
(2,0)
46
(3,0)
40
V9
V8
K = 0
26
30
V7
24
28
V6
49
V5
20
54
V4
V3
V2
V1
V0
50
52
22
(N+1, 0)
(N+1, N+1)
56
10

FIG. 1

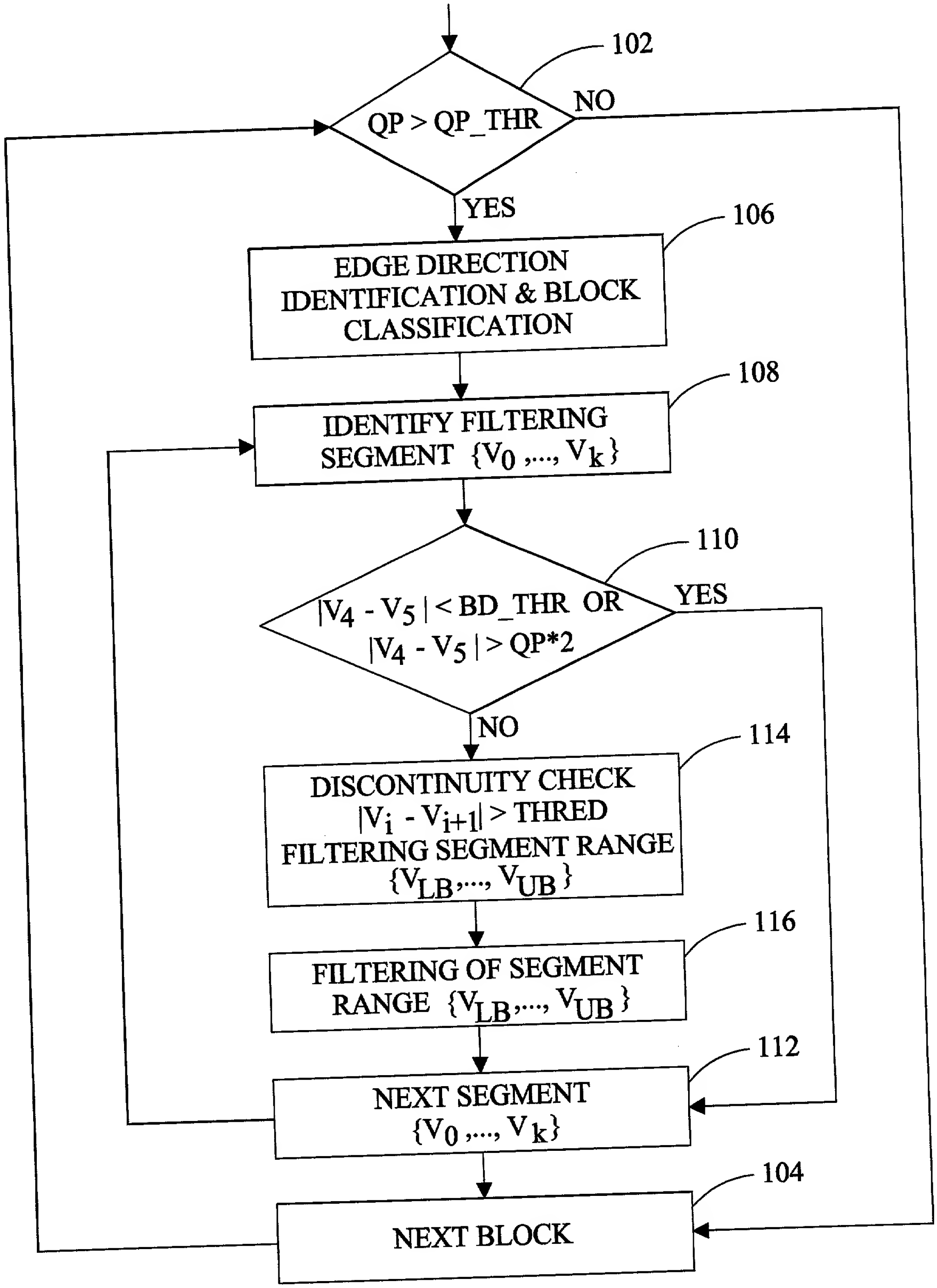
102
QP > QP_THR
NO
YES
106
EDGE DIRECTION IDENTIFICATION & BLOCK CLASSIFICATION
108
IDENTIFY FILTERING SEGMENT {V0 ,..., Vk}
110
|V4 - V5| < BD_THR OR |V4 - V5| > QP*2
YES
NO
114
DISCONTINUITY CHECK |Vi - Vi+1| > THRED FILTERING SEGMENT RANGE {VLB,..., VUB}
116
FILTERING OF SEGMENT RANGE {VLB,..., VUB}
112
NEXT SEGMENT {V0 ,..., Vk}
104
NEXT BLOCK

FIG. 2

DECLARATION AND POWER OF ATTORNEY

As the below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name,

I believe I am the original, first and sole inventor of the subject matter which is claimed and for which a patent is sought on the invention entitled:

A METHOD OF DIRECTIONAL FILTERING FOR POST-PROCESSING COMPRESSED VIDEO

the specification of which is attached hereto.

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claim(s), as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, § 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, § 119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s)

			Priority Claimed
(Number)	(Country)	(Day/Month/Year Filed)	[ ] Yes [ ] No
(Number)	(Country)	(Day/Month/Year Filed)	[ ] Yes [ ] No

I hereby claim the benefit under 35 U.S.C. § 119(e) of any United States provisional application(s) listed below.

(Application Serial No.) (Filing Date)

I hereby claim the benefit under Title 35, United States Code, § 120, of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States

application in the manner provided by the first paragraph of Title 35, United States Code, § 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, § 1.56 which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

(Application Ser. No.)	(Filing Date)	(Status) (patented, pending, abandoned)

I hereby appoint Jacob E. Vilhauer, Jr., Reg. No. 24,885, Charles D. McClung, Reg. No. 26,568, Dennis E. Stenzel, Reg. No. 28,763, Donald B. Haslett, Reg. No. 28,855, William O. Geny, Reg. No. 27,444, J. Peter Staples, Reg. No. 30,690,Kevin L. Russell, Reg. No. 38,292, Bruce W. DeKock, Reg. No. 40,585, Nancy J. Moriarty, Reg. No. 40,733, and Timothy A. Long, Reg. No. 28,876, all of the firm of Chernoff, Vilhauer, McClung & Stenzel, LLP, 1600 ODS Tower, 601 S.W. Second Avenue, Portland, Oregon 97204, telephone number 503-227-5631, my attorneys, jointly and individually, to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Dated: 3/30/2000

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE UNDER 37 CFR §3.73(b)

Applicant: Wenjun Zeng

Application No: N/A Filed: Concurrently herewith

Title: **A METHOD OF DIRECTIONAL FILTERING FOR POST-PROCESSING COMPRESSED VIDEO**

Sharp Laboratories of America, Inc. (Assignee)a Washington corporation (Type of Assignee, e.g., corporation, partnership, university, government agency, etc.)certifies that it is the assignee of the entire right, title and interest in the patent application identified above by virtue of either:

A. [ ] An assignment from the inventor(s) of the patent application identified above. The assignment was recorded in the Patent and Trademark Office at Reel ____, Frame ____, or for which a copy thereof is attached.

OR

B. [ ] A chain of title from the inventor(s), of the patent application identified above, to the current assignee as shown below:

1. From: ____________ To: ______________
The document was recorded in the Patent and Trademark Office at Reel ___, Frame ___, or for which a copy is attached.

2. From: ____________ To: ______________
The document was recorded in the Patent and Trademark Office at Reel ___, Frame ___, or for which a copy is attached.

[ ] Additional documents in the chain of title are listed on a supplemental sheet.

[x] Copies of assignments or other documents in the chain of title are attached. (Where one or more of the documents is unrecorded.)

The undersigned has reviewed all the documents in the chain of title of the patent application identified above and, to the best of undersigned's knowledge and belief, title is in the assignee identified above.

The undersigned (whose title is supplied below) is empowered to sign this Certificate on behalf of the assignee.

I hereby declare that all statements made herein of my own knowledge are true, and that all statements made on information and belief are believed to be true; and further, that these statements are made with the knowledge that willful false statements, and the like so made, are punishable by fine or imprisonment, or both, under Section 1001, Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Date: March 31, 2000

Name: Timothy A. Long

Title: Attorney for the Assignee (a copy of the Power of Attorney is attached)

Signature: Timothy A. Long

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